Imaging the Lung under Pressure

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Award Number: N0001409WR20203
http://www.whoi.edu

LONG-TERM GOALS

This study is aimed at improving our understanding of the mechanical properties of the respiratory system for a range of diving mammals to improve our ability to predict gas exchange during diving. In particular, our study aims to answer at what depths the alveoli of marine mammals collapse. We will also determine if differences in the anatomy of the respiratory system result in significant species differences in collapse depth. This is vital to understand how diving mammals manage inert and metabolic gases during diving.

OBJECTIVES

Our main objectives are to measure the elasticity (compliance) of the lower (alveoli) and upper (trachea and bronchi) respiratory system in marine mammals (seal and dolphin). These measurements will be used to model volumes of the respiratory system in deceased marine mammals at varying pressures (depths). A major question to answer is if there are species differences in respiratory compliance values. If so, that would result in large differences in collapse depth for animal diving with the same lung volume. A previously mathematical model will be revised. We will determine if a model

Report Documentation Page

Form Approved OMB No. 0704-0188

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**
4. TITLE AND SUBTITLE **Imaging The Lung Under Pressure**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Woods Hole Oceanographic Institution,Biology Department,Mailstop 50, Biology Department,Woods Hole,MA,02543**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This study is aimed at improving our understanding of the mechanical properties of the respiratory system for a range of diving mammals to improve our ability to predict gas exchange during diving. In particular, our study aims to answer at what depths the alveoli of marine mammals collapse. We will also determine if differences in the anatomy of the respiratory system result in significant species differences in collapse depth. This is vital to understand how diving mammals manage inert and metabolic gases during diving.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**3**	

with 2 compartments with varying compliances suffice to predict respiratory volumes in all species or do some species require additional compartments (e.g. air sinuses)?

APPROACH

The proposed methods are separated into two units, A: Computed tomography and associated analyses of respiratory volumes; B: Mathematical modeling to predict respiratory volumes and the level of gas exchange.

A) Ultra-high resolution spiral CT scanning techniques will be used to determine volumes of the respiratory system and alveolar collapse depth in different species of marine mammals. We will use newly deceased, either stranded or bycaught, animals. The cadaver is placed inside the pressure vessel and the lungs inflated with varying volumes of air. The volume of air injected is meant to simulate an animal with a diving lung volume of 100%, 70%, and 20% of the total lung capacity.

We scan the cadavers at varying pressures allowing us to determine pressure-volume loops of the upper and lower respiratory tracts. Specialized 3D imaging software will be used to estimate the air volumes in the various parts of the respiratory system at each pressure. The trans-thoracic pressures, respiratory volumes and initial diving lung volumes will be used to generate pressure-volume loops (compliance curves) for the different compartments of the respiratory system.

B) The relationship between internal volumes and trans-thoracic pressures will be used to generate pressure volume-loops for the upper and lower respiratory tract. The compliance values will be used to re-parameterize a previously published mathematical model and allow testing of the hypothesis that differences in the physical characteristics of the respiratory system result in large differences in blood and tissue N_2 levels in deep versus shallow diving marine mammals.

In toothed whales, the highly re-enforced air sinus is predicted to have very low compliance, although the ventricles lateral to the upper airway will likely be highly compliant. If so, the model used to predict respiratory volumes will have to be modified to include a third compartment.

WORK COMPLETED

In the first year of this study, we have completed the design, fabrication and testing of the pressure chamber. We have performed some initial experiments to acquire images of seals and porpoises at different pressures and with different initial diving lung volumes.

While setting up the hyperbaric chamber we did some preliminary experiments to measure the relationship between pressure and volume of the respiratory system in various marine mammals. We expect to continue this work in the next fiscal year by completing the chamber experiments.

RESULTS

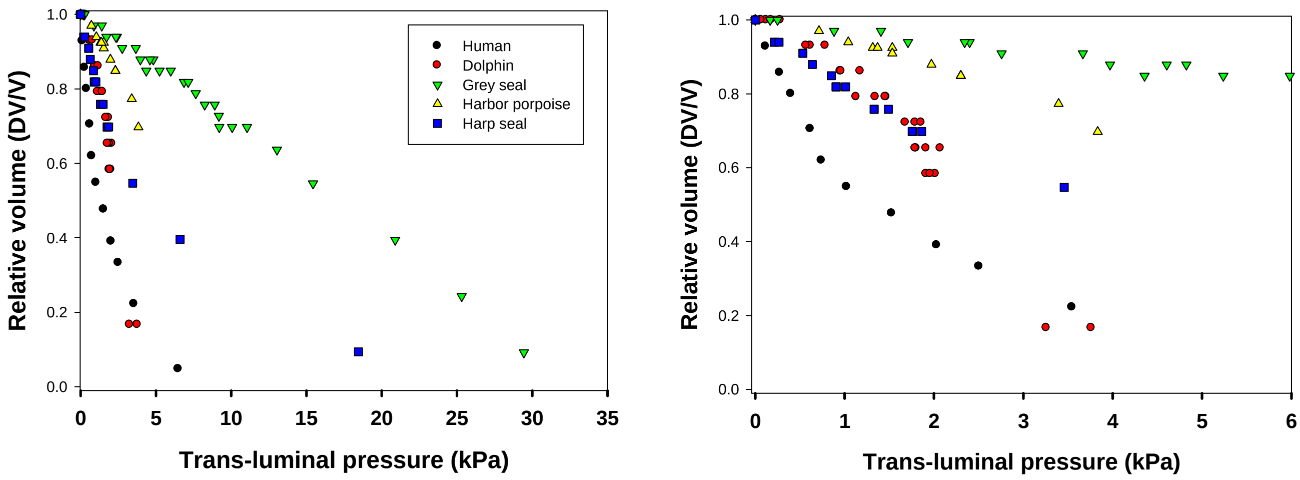

Figure showing the relationship between inside and outside pressure (trans-luminal pressure and the relative volume in the trachea of a range of mammals.

The figure shows how internal pressure increases as the trachea is compressed. The figure also shows the large range in compliances between different species, with the grey seal being the least compliant. With a total lung capacity (TLC) of 11 l, and a trachea and bronchi of 1 l, alveolar collapse would occur at 108 m for a grey seal, 150 m for a harp seal and 250 m for a human.

IMPACT/APPLICATIONS

This work is intended to enhance our understanding of how the lungs compress during breath-hold diving in marine mammals. The results will provide a mathematical description that relates diving lung volume, and depth to alveolar volume during breath-hold diving. The study will also establish proof-of concept for a new generation of hyperbaric chambers that allow imaging under pressure.

Results from the proposed study will help to improve our understanding about the physiology of marine mammals and improve modeling efforts that are aimed at estiamting inert gas levels in breath-hold divers. The results can be used to determine how changes in dive behavior, from playback studies that measures avoidance patterns in deep diving whales, affect blood and tissue P_{N_2} levels. Thus, these data will enhance the fundamental understanding, interpretation and avoidance of the effect of anthropogenic sound, and enable knowledgeable decisions about sonar deployment, related training exercises and responses to NGO concerns. This should be of value to the US Navy Marine Mammal Program.

RELATED PROJECTS

Dr. Michael Moore is the PI on a related project where the hyperbaric CT chamber is being developed. The chamber is used for the experiments conducted in this study.